Hydraulic Fracturing: Preliminary Analysis of Recently Reported Contamination

September 2009

Prepared for:
Drinking Water Protection Division (DWPD)
Office of Ground Water and Drinking Water (OGWDW)
U.S. Environmental Protection Agency (EPA)

Prepared by:
The Cadmus Group, Inc.
57 Water Street
Watertown, MA 02472

DIM0036987

Table of Contents

Preliminary Analysis of Recently Reported Contamination

Executive Summary

In June 2004, EPA released a report entitled, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs.* This study was a limited-scope assessment to help the Agency determine: 1) the potential for the injection of hydraulic fracturing fluids into coalbed methane wells to threaten underground sources of drinking water (USDW); and 2) whether additional study was warranted (USEPA, 2004). Based on its research, EPA concluded that the injection of hydraulic fracturing fluids into coalbed methane wells poses little or no threat to USDWs and did not justify additional study at the time of the 2004 EPA report.

Recently, natural gas production from gas-bearing shales in the United States has increased significantly with hydraulic fracturing playing a key role in gas production from these types of gas reservoirs. This production expansion has occurred in new geographic regions and different (non-coalbed) geologic formations than those previously studied by EPA. Increasing public and congressional concerns of possible contamination relate to the greatly expanded natural gas production and recent reports of production-related incidents of drinking water contamination. In response, EPA is reviewing post-2004 incidents of drinking water contamination that may stem from hydraulic fracturing and is also reviewing any new information related to older (pre-2004) cases.

The purpose of this review is to: 1) provide a characterization of the reported incidents of contamination; and, 2) identify whether a direct link has been established in the reported incidents between ground water contamination and hydraulic fracturing activities.
Information for the 2009 report is based on contamination incidents identified in Arkansas, Colorado, New Mexico, Ohio, Pennsylvania, Texas, and Wyoming that were obtained from various news articles identified through internet searches (see Appendix A for search terms), state environmental investigation reports, and from anecdotal information provided to the Agency by outside sources. The available documentation varied greatly in quality and detail, ranging from brief descriptions of the incident to detailed investigative reports by state agencies.

Complaints involving private drinking water well contamination included changes in water quality (murky, oily, rusty, foul tasting or smelling water, the presence of methane), changes in water quantity, consumption of the water causing illness in people (adrenal tumor, nausea, headaches), and rashes after showering.

Some reported incidents did not clearly identify whether hydraulic fracturing was conducted in the gas production well, or wells, associated with the reported (or alleged) water contamination problem, while others did not identify hydraulic fracturing as the specific cause. In addition, confounding factors, including other gas production-related releases that were reported by citizens and state agencies (e.g., accidental spills during operation and transport, improper management and construction of by-product fluid impoundment pits, improper burning of wastes, and air emissions) make it difficult to link water impacts specifically to hydraulic fracturing activities. Further, for those sites with ground water contamination allegedly linked to hydraulic fracturing activities, the information identified to date on production or site geology and hydrogeology is inadequate to definitively confirm --or rule out-- hydraulic fracturing as the cause of the contamination.

Twelve of the contaminant cases described in this report may have a possible link to hydraulic fracturing, but, to date, EPA has insufficient information on which to make a definitive decision. These incidents are located in six states in the following counties, towns, or townships:

- Huerfano County, CO
- La Plata, CO
- San Juan, NM
- Bainbridge Township, OH
- Bradford Township, PA
- Gibbs Hill, PA
- Hamlin Township, PA
- Dimrock Township, PA
- Millcreek Township, PA
- Grandview Johnson, TX
- Pavillion, WY
- Pinedale, WY.

As a next step, EPA plans to contact its regional offices, state regulatory agencies, and other key individuals to obtain additional follow-up information on each of these 12 reported cases. EPA will provide a summary of the information obtained from these sources in an addendum to this report.

Background

In June 2004, EPA released a study entitled, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs*. This study was a limited-scope assessment to help the Agency determine: 1) the potential for the injection of hydraulic fracturing fluids into coalbed methane wells to threaten underground sources of drinking water (USDW); and 2) whether additional study was warranted (USEPA, 2004).

Hydraulic fracturing is the injection of fluid under pressure to facilitate the production of oil and natural gas. In hydraulic fracturing, a fluid (usually water containing specialty high-viscosity fluid additives) is injected into underground rock formations under high pressure. The pressure exceeds the rock strength, and the fluid opens or enlarges fractures in the rock. These larger, man-made fractures start at the injection well and extend as much as several hundred feet into the reservoir rock. After the formation is fractured, a propping agent (usually sand carried by the high-viscosity additives) is pumped into the fractures to keep them from closing when the pumping pressure is released (http://www.epa.gov/safewater/uic/wells_hydrofrac.html).

As part of the 2004 report, EPA:

- Compiled existing information on the process and practice of hydraulic fracturing and the coalbed reservoirs in which this activity occurs;

- Published a request in the *Federal Register* for information on USDW contamination believed to be associated with hydraulic fracturing of coalbed methane (CBM) wells; and

- Reviewed reported incidences of potential ground water contamination due to hydraulic fracturing and any follow-up actions or investigations to identify possible links to hydraulic fracturing practices.

Based on its research, EPA concluded that the injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs and did not justify additional study at the time of the 2004 EPA report.

In the five years since the 2004 EPA report was published, the number of natural gas production wells employing hydraulic fracturing techniques has increased significantly in the United States. Also increasing over this period are the concerns expressed by the public and Congress regarding hydraulic fracturing and its impacts on ground water. Recent news articles report USDW contamination from oil and natural gas exploration activities (for example see "Controversial path to possible glut of natural gas," The *Christian Science Monitor*, September 17, 2008; "Drilling process causes water supply alarm," *Denver Post*, November 17, 2008; and "Water woes, Wells contaminated at site of gas leak," *Erie Times News*, July 16, 2008).

In 2009, EPA Administrator Lisa Jackson received questions regarding reports of "more than a thousand cases of contamination" and their link to hydraulic fracturing during a subcommittee meeting of the U.S. House of Representatives in May, 2009. Hydraulic fracturing is currently exempt from regulation under the Safe Drinking Water Act (SDWA) but both the House and Senate have introduced bills that, if passed, will remove this exemption from SDWA.

In response to these recent events, EPA is reviewing reports of contamination incidents believed to be linked to hydraulic fracturing since 2004 and new information related to older reported cases. The purpose of this report is to: 1) provide a characterization of the reported incidents of contamination, and, 2) identify whether a direct link has been established between ground water contamination and hydraulic fracturing activities.

This report is based on information obtained from internet searches (see Appendix A for search terms) and from anecdotal information provided to the Agency by outside sources.[1]

---

[1] EPA received reports of "more than a thousand cases of contamination" of drinking water due to hydraulic fracturing. This statement is believed to be based on a November 17, 2008 *Denver Post* article of a *ProPublica* investigation, "Drilling process causes water supply alarm", which described water contamination in drilling areas in the United States (Lustgarten, 2008). This article stated that, "… more than 1,000 other cases of contamination have been documented by courts and state and local governments in Colorado, New Mexico, Alabama, Ohio and Pennsylvania." This article describes ground water and surface contamination incidents from drilling, spills and improper management of waste pits, and does not attribute all these incidents to hydraulic fracturing activities.

The report contains two parts, 1) a summary of reported cases of hydraulic fracturing contamination and 2) conclusions that can be drawn from the information and follow-up actions the Agency could take to collect additional data on hydraulic fracturing.

Summary of Reported Contaminant Cases

For this report, EPA reviewed contamination cases reported in Arkansas, Colorado, New Mexico, Ohio, Pennsylvania, Texas, and Wyoming and any follow-up actions that have been taken. The sources of information used to prepare the following summaries varied greatly in quality and detail, ranging from little more than a brief description of the incident to those where investigative reports were available. The wide range of technical information is included in the summaries partly to catalog the type of information typically available. For some, hydraulic fracturing is not explicitly stated as the oil and gas activity alleged to be the source of the ground water contamination. A few of the incidents included in this report involve non-ground water complaints (e.g., direct contact with hydraulic fracturing fluid or improper handling and disposal practices involving these fluids). These are included to provide some perspective on the breadth of complaints that have been reported involving hydraulic fracturing practices. This report does not include a discussion of surface water contamination or water use issues (e.g., water source to be used in the fracturing process).

Arkansas

The following discussion of reported contamination believed to be associated with oil and gas activity in Arkansas, is summarized from a July 5, 2009 article in the *Arkansas Democrat-Gazette* (Stevens, 2009).

Summary

A July 5, 2009 article in the *Arkansas Democrat-Gazette* reported private well-water problems associated with drilling activities performed by Southwestern Energy Co. in the Fayetteville Shale natural gas drilling area, which spans north-central Arkansas (Stevens, 2009). The author notes that there are over 1,300 natural gas wells drilled into the shale zone. Rebecca and Jerry Cockrell are reported to be among at least a dozen residents in the area who have complained about contamination of their drinking water wells from drilling activity. According to the article, the Cockrells noticed a change in their water quality in December 2006 after Southwestern Energy Co. began drilling natural gas wells within a few hundred feet of their home. They indicated that their water changed in appearance (was murky, orange or gray in color), contained pebbles, and left a filmy deposit on their water glasses. After a second well was drilled, the Cockrells reported a bad sulfur smell while running the water from their private well, making it difficult for them to remain in their home. The Cockrells initially installed an expensive filtration system and ultimately connected to city water, spending about $12,000. XTO Energy bought the drilling section from Southwestern, and when the Cockrells informed the company of their problems, XTO offered a $6,000 settlement if the Cockrells did not hold XTO or previous parties liable for their water issues.

The same July 5 article also described a complaint from a resident of Bee Branch, Arkansas, whose water became cloudy for a few days after Southwestern Energy conducted seismic work near her home. According to the article, Charlene Parish observed a permanent change in her well water after a natural gas well was fractured near her property. Her water became yellow and muddy and silt accumulated in her toilets when unused overnight. She also noted that her tenant's water smelled of "sulfuric acid". After using bottled water for months, Parish connected her home and her tenant's home to the local public water system.

Another complaint described in the July 5 article was made by a resident of Pangburn, Jeff Graetz. He noted that water from his well turned muddy and contained very light and slick particles after fracturing was performed by Southwestern Energy Co. in September 2007 on a well that is about 600 feet from his home. He indicated that his water quality eventually improved after fracturing activities ceased. The article discusses other complaints believed to be caused by drilling operations (hydraulic fracturing is not specifically mentioned). These complaints include water that was muddy, oily, or rusty in appearance; water with a high sediment content; and low water levels. The article indicates many of these individuals ended up connecting to public water systems and that public water system administrators know of other residents in the Fayette Shale natural gas drilling area who have done the same after water quality declined following nearby drilling activities.

Actions Taken

According to the article, well water complaints have been reported to each of the four Arkansas agencies with water-quality oversight responsibilities: the Oil and Gas Commission, the Department of Environmental Quality (DEQ), the Health Department, and the Natural Resources Commission. However, none of these agencies regulates private well water directly. Tests performed by each of these agencies on complainants' water found no traces of drilling fluid chemicals. The article lists possible components of fracturing fluids as including acetone, arsenic, benzene, cyanide, mercury, lead, uranium, zinc, oil, grease, and chloride. The article does not specify which chemicals were included in the analyses of the complainants' well water samples other than to indicate that DEQ's analyses included iron and manganese (*see "Possible Explanations for Decline in Water Quality" below*).

Possible Explanations for Decline in Water Quality

The article provides some theories on the decline in water quality posed by the Oil and Gas Commission, Southwestern Energy, the University of Arkansas, and the Arkansas Geological Survey. The Oil and Gas Commission Director noted that there "may have been a disruption of that near-surface water due to mechanical influences of the operation." Water quality may have been changed by the drill bit cutting through the aquifer, but the director noted that it was difficult to prove that drilling caused contamination "because there's nothing you can measure." The Arkansas DEQ reported that elevated levels of iron and manganese were found, but these elements occur naturally in ground water in the state.

Alan Stubblefield, Senior Vice-President of Southwestern Energy for Arkansas operations, maintained that "there's no way the company's drilling would cause the kinds of water-well problems experienced by Parish and the Cockrells." The company also noted that fracturing occurs between 1,500 and 6,500 feet below the surface and that it would take hundreds or thousands of years for drilling fluid to migrate to the surface or to affect drinking water. The company also stated that it monitors well bores, "investigates anything out of the ordinary during the process", and has a protocol to "try to handle" and prevent problems to drinking water wells; the article did not elaborate on these measures. In addition, a contractor for Southwestern noted that there has been no contamination by drilling fluids, although ground shake and large equipment may cause "problems" for water wells in the area.

Ralph Davis, Chairman of the University of Arkansas' geosciences department, indicated that natural gas drilling should not impact drinking water sources if companies are following the Oil and Gas Commission regulations. He stated that the drinking water sources are shallow in the drilling area of the Fayetteville Shale and that changes in water quality including turbidity, color, and smell can occur for several reasons. He noted that the shallow water sources are "open to rapid recharge from the surface." Therefore, rain or snow melt could carry surface contaminants into the shallow sources of drinking water.

William Prior of the Arkansas Geological Survey indicated that his office has received complaints about water quality degradation after drilling but has not tracked the complaints. He explained that water from the Fayetteville Shale is different from other aquifers in the state in that it comes from several "shallow crevices, fractures, and holes." If drilling hits the same fracture system that is supplying a private well, it can drain the water in that fracture system. He added that any major disturbance, including major construction or building a freeway, can affect ground water in that area. He also noted that he did not "have the answers as to provability as far as cause and effect."

Colorado

Contamination incidents are discussed below for Garfield County, LaPlata County, and the towns of Durango and Platteville, Colorado.

Garfield County

The following summary of reported contamination in Garfield County is based on a June 10, 2005 Notice of Hearing from the Colorado Oil and Gas Conservation Commission (COGCC) (COGCC, 2005a), an October 2007 article written by the Natural Resources Defense Council (NRDC) (Mall et al., 2007), and an article posted to the Oil and Gas Accountability Project (OGAP) website (Sumi, 2006). Information regarding 2-BE, a surfactant that is sometimes used in fracturing fluid is based on a November 17, 2008 *Denver Post* article (Lustgarten, 2008) and a Halliburton Energy Services Material Safety

Data Sheet (Halliburton Energy Services, 2007). Other materials summarized include three large studies that characterize the hydrogeology of the Mamm Creek Field Area in Garfield County.

Summary

On April 30, 2001, staff at the COGCC received a complaint from Mr. Harland Walker (co-owner of the Amos/Walker water well) alleging impacts to his water well from the nearby oil and gas wells. Mr. Walker complained that his well had begun to produce smelly, dark gray, "fizzing" water and that his well yield had decreased. His well is located within the Mamm Creek area of Garfield County, Colorado. He stated that the problems had begun a week or two earlier. On May 1, 2001, COGCC staff received a similar complaint from Mr. Larry Amos (co-owner of Amos/Walker water well) stating that the well cap had blown off and that gray fizzy water gushed from the well (COGCC, 2005a).

Ms. Laura Amos later lodged a complaint that she suffered from an adrenal tumor diagnosed in 2003 (Mallet al., 2007). She believed the tumor was caused by a surfactant, butanol, and ethylene glycol monobutyl ether (2-BE). According to the article, these chemicals were used by an energy company during the hydrofracturing process in at least one natural gas well adjacent to her drinking water well (COGCC, 2005a). At the time of the diagnosis, Ms. Amos was unaware of the use or health effects of 2-BE (Mall et al., 2007).

According to a 2008 *Denver Post* article, 2-BE is a clear, odorless surfactant that is sometimes used in foaming agents in hydraulic fracturing ("fracing") fluids (Lustgarten, 2008). This article also indicated that investigations conducted by Theo Colborn, an independent Colorado-based scientist who specializes in low-dose effects of chemicals on human health, indicate that exposure to the chemical can cause adrenal tumors. In addition, the Halliburton Energy Services Material Safety Data Sheet for 2-BE indicates that exposure may cause skin, liver, kidney, lung, and blood disorders, fetal damage and testicular cancer (Halliburton Energy Services, 2007).

Between January, 2001 and March, 2001, Ballard Petroleum, LLC ("Ballard") drilled four gas wells located in the SW¼ NE¼ of Section 33, Township 6 South, Range 92 West, 6th P.M. in the vicinity of the Walker drinking water well. These gas wells are known as the Boulton No. 33-2, 33-7, 33-8, and 33-9 wells. The wells were drilled into the Williams Fork Formation. (Typically production well depths in the Williams Fork Formation in this vicinity are greater than 6,000 feet below ground surface or bgs.) Drilling records indicate that natural gas was not observed in the shallower Wasatch Formation (which overlies the Williams Fork Formation) during the drilling of these wells, and no unusual conditions were encountered. Between January and June 2001, the gas wells were completed and hydraulically fractured Alberta Energy Corporation became the operator of the Boulton wells on December 31, 2001 (COGCC, 2005a). This responsibility was assumed by EnCana Oil & Gas (USA) Inc. on June 1, 2002. (Note: Well construction details were not provided for the four 'Boulton 33' wells (e.g., casing and cementing depth, construction problems encountered, fracturing intervals) nor their specific surface locations or subsurface locations as determined by directional drilling of the wells.

The Amos/Walker well is located in the SE¼ of Section 33, Township 6 South, Range 92 West, 6th P.M. The well was completed on May 26, 1981 for Divide Creek Land and Cattle Company under Colorado Division of Water Resources water well Permit No. 113065. The total depth of the well is 225 feet bgs, and at the time of completion, the well had a static water level of 68 feet bgs. The well was permitted as a domestic water well that could be used to supply water to not more than three (3) single family dwellings for normal household purposes, fire protection, and the irrigation of not over one (1) acre of home gardens and lawns (COGCC, 2005a).

Actions Taken

In 2005, EnCana was fined $266,000 by the State of Colorado for "failure to protect water-bearing formations" because of natural gas migration into the Wasatch Formation. COGCC staff review indicated that fracturing stimulations were confined to the intended formation interval. None of the stimulation records exhibited the severe pressure losses that would have occurred if the stimulation had communicated with the shallow fresh water aquifer, and analytical results from extensive water sampling of nearby water wells indicate that no fracturing fluids were ever found to be present in the ground water (COGCC, 2005a). Separate from the Agency response, Ms. Amos sued the drilling firm EnCana, and in 2006 accepted a multimillion-dollar settlement from the company.

Analyses conducted on samples collected during eight sampling events in 2001 and 2004 indicated that ground water contamination at the Amos/Walker water well is limited to methane, ethane, propane, n-butane, iso-butane, n-pentane, iso-

pentane, and hexane. Analyses of the gas in the production wells and gas found in the Amos/Walker water well were "isotopically and compositionally similar". To date, benzene, toluene, ethylbenzene, and xylenes (BTEX) have not been detected in the Amos/Walker water well. In addition, because large quantities of sodium, potassium, and chloride were used in the fracturing fluid, samples were also analyzed for these elements. Elevated levels of these chemicals were not found in the samples. The COGCC concluded that the ground water impacts at the Amos/Walker water well were not a result of hydraulic fracturing but were most likely caused by inadequate isolation of the Williams Fork Formation, which resulted in higher than normal bradenhead pressures and gas migration up into the Wasatch Formation (COGCC, 2005a).

A fact sheet provided by Chesapeake Energy (Chesapeake Energy, 2009) indicates that microseismic mapping was conducted in the area "at the time", which "showed the fractures created as a result of fracing activities were not oriented in the direction of the Amos well, rendering the flowing of those fluids toward the well a virtual impossibility." Mention of this microseismic mapping was not found in any of the other documents reviewed for this report.

Other Reported Complaints in Garfield County

The following complaints involving the Bill Barrett Corporation drilling operations and resulting COGCC action were summarized from an article posted to the Oil and Gas Accountability Project (OGAP) website (Sumi, 2006). OGAP, a program of Earthworks, tracks incidents of oil and gas chemicals and waste in Colorado. According to OGAP, COGCC received ten complaints relating to foul odors "emanating from wells being drilled and completed by Bill Barrett Corporation" during September through December, 2005. In each complaint, homeowners indicated that the fumes from the wells prevented them from being outdoors. In addition, one family complained of headaches, and another of nausea.

COGCC issued nine Notices of Alleged Violation (NOAVs) to Barrett during this time for: transporting condensate wastes without a permit; over-filling the pits; burning wastes at unauthorized sites; not reporting the hydraulic fracturing flowback spill outside the pit; and not removing pit condensate within 24 hours. One Barrett employee noted that he was unaware of the pit-level requirements, and did not realize that requirements were being violated.

Regional Hydrogeologic Studies

This section provides information from three regional studies that characterize the hydrogeology of the Mamm Creek Field Area in Garfield County: Phase I Hydrogeologic Characterization of the Mamm Creek Field Area, Garfield County (URS, 2006); Phase II Hydrogeologic Characterization of the Mamm Creek Field Area, Garfield County, Colorado (Papadopulos, 2008), and; Review of Phase II Hydrogeologic Study Prepared for Garfield County (Thyne, 2008). The first two reports (URS, 2006 and Papadopulos, 2008) were prepared for the Board of County Commissioners, Garfield County, Colorado, with the initial scope of work defined in a March 2005 Memorandum of Understanding among COGCC, EnCana, the Board of County Commissioners, Garfield County, and several other parties. The origin of the third report (Thyne, 2008) is not stated.

The Amos/Walker well is located in the area reviewed by these three studies. However, the studies are regional in nature and did not conduct an investigation or present any findings specific to the Amos/Walker well incident or on any other reported impacts to drinking water alleged to be associated with hydraulic fracturing.

All three studies investigated the ground water and surface water resources in the Mamm Creek Field Area and assessed their vulnerability to impacts from natural gas operations and other human activities. These reports provide valuable background and regional baseline information regarding water quality, hydrogeology, geology, and regional fracture and fault systems. Extensive data were compiled and analyzed regarding the geochemistry of water collected from production wells, drinking water wells, monitoring wells, and surface water bodies. Thyne (2008) reviewed both the Phase I and Phase II reports, but also reviewed additional research and concluded that there was a regional trend in increased ground water concentrations of chloride and methane (to levels above natural background) that relate to the deeper gas-bearing Williams Fork Formation and likely to the gas production operations in the area. Thyne (2008) also concluded, though, that given the nature of the regional assessments conducted, it was difficult to assign responsibility for ground water impacts to specific gas wells: "The number of water wells (<200) and their spatial distribution is inadequate to monitor and locate potential source of contamination from the more than 1400 potential point sources (gas wells and produced water pits)." He stated that "Usually the identification of specific sources requires at least three monitoring points (wells) for each potential point source for determination of background and up-gradient water, and water down-gradient of potential sources."

Durango

The following information about an emergency-room nurse's exposure to fracturing fluids and state and federal response was presented in an August 20, 2008 *Newsweek* on-line article (Moscou, 2008). The cause of the fracturing fluid spill and additional information (contradictory to the Newsweek article) regarding the presence of fracturing fluid on the emergency room patient was reported in a July 23, 2008 *Durango Herald* article (Slothower, 2008). Additional information on Zeta-Flow (fracturing fluid) was taken from a material safety data sheet (Clearwater International, LLC, 2009).
The following information about an emergency-room nurse's exposure to fracturing fluids and state and federal response was presented in an August 20, 2008 *Newsweek* on-line article (Moscou, 2008). The cause of the fracturing fluid spill and additional information (contradictory to the Newsweek article) regarding the presence of fracturing fluid on the emergency room patient was reported in a July 23, 2008 *Durango Herald* article (Slothower, 2008). Additional information on Zeta-Flow (fracturing fluid) was taken from a material safety data sheet (Clearwater International, LLC, 2009).

Summary

Unless otherwise noted, the information presented below is based on an August 20, 2008 *Newsweek* article (Moscou, 2008).

On April 17, 2008, Cathy Behr, an emergency-room nurse in Durango, Colorado, treated Clinton Marshall, an employee at an energy-services company, Weatherford International. Marshall indicated that he was involved in a "fracturing-fluid" spill and complained of nausea and headaches. Behr indicated that the "chemical stench coming off Marshall's boots was buckling." As a precautionary measure, the hospital evacuated and locked down the emergency room, and its staff was instructed to don protective masks and gowns. However, Behr had been attending Marshall unprotected for 10 minutes. A few days later, Behr's skin turned yellow and she began vomiting and retaining fluid. She was admitted to the ICU with a swollen liver, erratic blood counts, and fluid-filled lungs and diagnosed with chemical poisoning.

Both the *Newsweek* and *Durango Herald* articles, reported that 130 gallons of ZetaFlow were accidently released. The *Durango Herald* article explained that the spill occurred when a valve to a tote containing fracturing fluids popped off during the operation. According to the *Newsweek* article, Marshall had the chemical "ZetaFlow" on him when he arrived at the emergency room. However, in his interview with the Durango Herald, Marshall indicated that he had removed his contaminated full protective gear (including a suit that covered his boots) prior to entering the hospital, and therefore did not believe that Behr had been exposed to ZetaFlow. *Newsweek* was unable to interview Marshall for their article but confirmed that the hospital contacted the Durango Fire and Rescue Authority to aerate the Emergency Room where Marshall was treated.

ZetaFlow is manufactured by Weatherford International. According to its Material Safety Data Sheet, ZetaFlow contains methanol and two "proprietary" compounds. It can be an "immediate" and "chronic" health hazard and prolonged exposure can cause kidney and liver damage, irritate lung tissue, decrease blood pressure, and result in dizziness and vomiting. Behr's physician noted that her symptoms were "entirely consistent with exposure [to ZetaFlow] from all the information we were able to gather."

A Material Data Safety Sheet that was updated after publication of the *Newsweek* article, indicates that ZetaFlow contains methanol, nitrogenated heterocyclic compounds, and proprietary phosphate ester (Clearwater International, LLC, 2009). In addition, to its immediate and chronic health hazards, it "may cause long-term adverse effects in the environment."

Actions Taken

An incident report for the April 17, 2008 spill of ZetaFlow was not filed. The spill occurred on the Southern Ute Indian Reservation. However, the Tribal authorities were not notified of the spill. OSHA, EPA, and COGCC indicated that the spill was outside their regulatory jurisdiction or was not significant enough to trigger reporting requirements. The Colorado offices of EPA and OSHA launched an investigation of the incident in August, 2008. (An additional internet search yielded no further information on the investigation.) Furthermore, La Plata County Commissioners are considering a new regulation that would require oil and gas companies to reveal hydraulic fracturing fluid chemicals to emergency room workers if someone is exposed. In addition, BP Corporation has reportedly suspended the use of ZetaFlow in hydraulic fracturing applications.

Huerfano County

Information regarding methane contamination in a number of wells in Huerfano County was based on a 2007 COGCC Report of the Commission (COGCC, 2007).

Summary

In the summer of 2007, methane seeped from the domestic well at the residence of Ben and Melanie Bounds in Huerfano County and exploded inside the pump house. A COGCC engineering field inspector for the Raton Basin visited the site and confirmed that gas was venting from the water well (COGCC, 2007). On June 9, 2007, the Bounds' well was inspected again, and a combustible gas indicator (CGI) confirmed that methane was venting from the well. The CGI meter readings exceeded 100% of the lower explosive limit (LEL) and showed 99% methane by volume. Water samples were collected from the well and submitted for analysis of dissolved methane, stable isotopes of methane, and inorganic parameters. Dissolved methane was detected at a concentration of 5.6 milligrams per liter (mg/L). The stable isotope results indicated that the methane venting from the Bounds' well is of thermogenic origin and is similar to Raton Basin coalbed methane (CBM) gas (COGCC, 2007).

Actions Taken

Based on water samples and/or CGI testing, COGCC determined that 11 of 37 drinking water wells in a 13-square mile area were contaminated with methane gas. COGCC and Petroglyph, Inc. agreed that Petroglyph would provide the affected households with drinking water, install methane detectors in the residences that had methane in their wells, assist in surveying other drinking water wells in the area for methane, and review well records for the potentially offending gas well, Lively #10-02 (COGCC, 2007). In addition, information was provided to the community on mitigating methane in drinking water wells, Petroglyph agreed to shut in their wells in Huerfano County, and a plan was developed for ongoing testing and mitigation of methane in drinking water wells in Huerfano County (COGCC, 2007). The USEPA plans to follow-up with COGCC to determine whether the state has identified the cause of the gas migration and if hydraulic fracturing was used in the completion and operation of the gas wells in the area.

La Plata County

The following report of drinking water well contamination from an unlined pit was summarized from a COGCC Notice of Alleged Violation (NOAV) issued to Maralex (COGCC, 2005b) and OGAP's website (Sumi, 2006).

Summary

COGCC was contacted on October 30, 2005 by Dave Thompson about potential drinking water well contamination from a nearby reserve pit. The unlined reserve pit is operated by Maralex Resources, Inc. and is located approximately 350 feet uphill from the drinking water well.

Actions Taken

COGCC collected samples from the well on November 1, 2005 and found higher levels of certain constituents relative to other wells in the area as follows: calcium (398 mg/L), chloride (890 mg/L), total dissolved solids (2320 mg/L), and electrical conductivity (3,120 us/cm). Based on these analytical results and those from additional water samples collected on December 28, 2005 and February 10, 2006, and "additional information", COGCC concluded that "fluids from the unlined reserve pit infiltrated into the shallow ground water, flowed downhill and impacted the Thomson water well."

COGCC issued a NOAV requiring Maralex to monitor the Thomas' and other wells downgradient from the pit for contamination and to provide Thomas with drinking water and/or provide and maintain a treatment system until they can demonstrate that the impacts to ground water contamination have been eliminated. In November 2005, the fluids from the pit were removed, and the pit was backfilled and closed.

A 2006 OGAP article indicated that ethoxylated nonylphenols; isopropanol; 2-bromo-2-nitropropane-1,3-diol; acrylamide and dipropylene glycol monomethyl ether; hydrochloric acid; and hydrofluoric acid were all used in different stages of the drilling process (Sumi, 2006). The article expressed concern that COGCC had not required Maralex to analyze water samples for more complex additives and that Maralex had not provided COGCC with the constituents of two products used during its drilling operations: HAI-81M (an acid inhibitor), and Halad-344, both Halliburton products. Research by

OGAP shows that Halad-344 "may include N,N-dimethylformamide, 2-acrylamido-2-methylpropane sulfonic acid, and N,N-dimethyl acrylamide" but that the constituents of HAI-81M are unknown. (The OGAP article does not indicate whether these compounds are used in hydraulic fracturing.) Another point raised by this article is that without knowing the chemical composition of the fluids used in drilling, an individual with concerns about contaminated wells will not know "what chemicals to look for in his water samples." USEPA plans to follow-up with COGCC to obtain more information regarding the fluids removed from this pit.

Platteville (Arapahoe County)

The following report of surface contamination during a fracturing fluid operation was based on a brief article from OGAP's website (Sumi, 2006).

In October 2005, 168 to 210 gallons of fracturing fluid were released to the surface when a wellhead valve failed on the Cannon Land 7-35 well during a fracturing fluid operation performed by Kerr McGee. The fluids sprayed into the air and landed on pasture land. Approximately 15-20 gallons ended up in the Platteville Lateral irrigation ditch.

The fluid contained potassium chloride, DWP-931 (a surfactant run at 1.5 gallons per 1000 gallons of water), DWP-601 (a friction reducer run at 0.5 gallons per 1000 gallons of water). DWP-931 includes ethoxylated nonylphenol (15-49%), trimethylbenzene (3-7%), light aromatic naphtha (3-13%), oxyalkylated phenolic resin (15-40%), ethylbenzene (0-2%), xylene (3-13%), and isobutyl alcohol (10-30%). DWP-601 consists of ethoxylated nonylphenol (1-5%). The article does not include any sampling information or details regarding COGCC follow-up action. However, the article cites an October 4, 2005 memo from COGCC to the Colorado Department of Public Health, which notes that the spill was classified as non-significant. A copy of this memo could not be obtained from the internet.

New Mexico

The New Mexico Oil Conservation Division (OCD) maintains a list of sites (active or closed) regulated by their Environmental Bureau in which ground water has been contaminated from "leaks, spills, and releases of oilfield wastes or products." (http://www.emnrd.state.nm.us/ocd/documents/rptGeneralizedGWImpact_000.pdf). The tracking report identifies the company responsible for the site and includes the following categories of information for each site: date, facility name, permit number, facility type, ground water depth, fluid type, county, location, and status. Information is limited to specific codes used for each category. Neither the categories nor codes are defined in the report. For example, under facility type, a site is coded as "Pit", "Class V", "Tank Battery", "Pipeline" or "UNK" (unknown). In addition, classification of fluid type does not specifically list hydraulic fracturing fluid but is limited to the following four codes: "oil", "Prod Wtr" (Production water), "both", or "UNK" (unknown). Therefore, it is unclear how many cases of ground water contamination involving industry pits, Class V injection wells, or unknown origin are from improper handling of fracturing fluids or production water from hydraulic fracturing.

According to a summary prepared by OGAP of the data presented in the OCD tracking report (Earthworks, no date), over 700 cases of ground water contamination by the oil and gas industry have been documented by OCD. Fifty-four percent of the 734 contamination cases are due to oil and gas industry pits and 38% are due to oil and water pipelines. Seven instances of contamination are associated with brine wells, five with Class V injection wells, 50 with tank batteries, and 17 with unknown origin.

Ohio

Bainbridge Township (Geauga County)

The description of the incident and follow-up investigation were summarized from a 153-page 2008 report prepared by the Ohio Department of Natural Resources, Division of Mineral Resources Management (OHDNR, 2008).

Summary

Natural gas seepage into an aquifer caused an explosion that severely damaged a house in Bainbridge Township, Geauga County on December 15, 2007. No one was injured, but natural gas entered several homes via ground water wells due to

inadequate cementing of the production casing and some operational problems in one particular gas production well, English 1, in the investigation area.

Natural gas, the primary hydrocarbon in oil and gas wells in the County, is produced from several geologic formations including the Berea, Ohio Shale, Oriskany Sandstone, Newburg Dolomite and Clinton sandstone. The Ohio Valley Energy Systems Corporation (OVESC) started drilling the English #1 well on October 18, 2007. The well was drilled to a total depth of 3,926 feet. Drilling was finished on October 26, with the driller noting only a slight odor of sour gas at total depth. Surface casing was set and cemented from the surface down through glacial (unconsolidated) sediments into bedrock to a depth of 88 feet. Another, smaller diameter surface casing was then set and cemented (down through the larger surface casing) from the surface to a total depth of 253 feet. (This extended the second casing 50 feet down into the Berea aquifer.) An attempt was then made to run an open-hole geophysical log, but it was unsuccessful due to an obstruction at 3,658 feet that was assumed to be a buildup of filter cake from drilling mud and the shaley dolomite in the subsurface at that depth. The logging effort was abandoned, and the final production casing was set and cemented (down through the other two larger diameter casings described above) to a depth of 3,873 feet. Despite attempts, the casing could not be advanced any deeper.

During cementing of the production casing, the well "lost circulation," but cementing was completed. (Circulation is said to be lost when injected drilling fluid flows out of the wellbore into the surrounding geological formation through permeable zones or fractures, instead of circulating back up the wellbore.) Some of the cement pumped down the wellbore to set the production casing presumably flowed out of the wellbore into bedrock fractures. This loss of cement contributed to an insufficient cementing of the space between the production casing and the borehole. Subsequent cement logging indicated that the top of the production casing cement was much lower than estimated based on the volume of cement emplaced into the wellbore (supporting the presumption of cement loss into some type of fracture zone). Despite the indication of insufficient cementing, the well was completed (perforated from 3,720-3,740 feet and acid treated) and then hydraulically fractured. During the initial fracturing work, circulation of fracturing fluid was observed in the annulus (the space between the production casing and the smaller surface casing), indicating hydraulic communication between the deep Clinton formation and the relatively shallow production casing annulus.

Work proceeded for several days to recover the fracturing fluid that had been displaced into the well annulus, and the annulus was then shut-in while work continued to complete the wellhead construction in preparation for production. For several days, pressure readings were made of the small surface casing annulus, and occasionally the pressure was released ("bled off"). The well was then shut-in (the annulus was closed), and no personnel were on the site for the following month prior to the natural gas explosion on December 15.

The Ohio Department of Natural Resources, Division of Mineral Resources Management (DMRM) determined that high-pressure gas from the deep Newburg or Clinton reservoir migrated up into and accumulated in the surface-production casing annulus of the well between November 13 and December 15, 2007. This resulted in over-pressurization of the annulus, causing the migration of the natural gas from the well annulus through natural fractures in the bedrock below the base of the cemented surface casing. This gas migrated vertically through the fractures into the overlying aquifers that served as drinking water sources and were pumped by domestic wells.

On the morning of December 15, methane gas entered the basement of a home at 17975 English Drive and ignited, causing an explosion that seriously damaged the house. Subsequent to the explosion, it was learned that gas had been detected in the drinking water well at the Bainbridge police station on December 12 (a well that was 280 feet deep and is approximately 4,700 feet northeast of the English 1 well). Also, there were reports of natural gas, turbidity increases, and artesian flow in the wells of some of the homes on English Drive. Immediately following the explosion, officials began checking gas levels in surrounding homes and drinking water wells. By the end of December 15, residents of 19 homes had been evacuated.

Actions Taken

Within days of the incident, OVESC stopped as much as 95% of the flow of deep gas to the aquifer by squeezing cement into the annular space between the borehole, production casing and spaces near the surface casing. OVESC, "disconnected 26 water wells, purged gas from domestic plumbing/heater systems, installed vents on six water wells, plugged abandoned in-house water wells, plumbed 26 houses to temporary water supplies, provided 49 in-house methane monitoring systems for homeowner installation, and began to provide bottled drinking water to 48 residences upon request." With the exception of the home damaged by the explosion, all residents were back in their homes by December 24, 2007.

The 2008 OHDNR investigative report contained monitoring data from a major sampling initiative of 79 wells beginning in February 2008. Most drinking water wells in use were approximately 100-250 feet deep. Water was monitored inside well enclosures and casings, as well as inside homes at hot and cold water taps. Air was monitored in confined spaces and outdoors. Original data sheets for some of the over 10,000 data points were included in the 153-page 2008 report. The site history and hydrogeologic setting were discussed in detail based on well logs and geologic evaluations collected before and after the explosion.

As a result of this comprehensive investigation and the data referenced in this report, the OHDNR DMRM issued an official finding of fact. It indicated that the OVESC English No. 1 well was improperly constructed so that it allowed the space between the surface casing and the production casing to become over-pressurized. This forced natural gas (methane gas and dissolved methane) into natural fractures in the bedrock below the base of the cemented surface casing, and into the surrounding aquifer. The gas found its way to residential wells, which acted as natural conduits for the gas to flow to the surface, and allowed it to build up in confined spaces in homes. Although methane in the wells generally dissipated, some methane persisted (at the time the report was written) in 23 drinking water wells, including a public supply and 22 private wells.

There are no federal primary or secondary drinking water standards for methane and no Ohio health-based standards. Natural gas (methane) has no smell and is relatively non-toxic, but it does pose a risk of explosion at sufficiently high levels. The highest concentration of dissolved methane in the 79 wells sampled by the OHDNR in 2008 was 1.04 mg/L. According to the Federal Office of Surface Mining Reclamation and Enforcement (OSMRE), levels of methane less than 10 mg/L require no immediate action, but periodic monitoring should be performed to verify that the gas concentration does not change. In-home testing revealed a maximum level of only 0.8 percent of the lower explosive limit (LEL). At this concentration, natural gas would have to increase over 125-fold to result in explosive conditions. Extensive sampling of ground water was also conducted, including for compounds used as additives in hydraulic fracturing fluids (ethanol, ethylene glycol, and isopropyl alcohol). The DMRM stated that ground water was not impacted by oilfield brines, crude oil, hydraulic fracturing fluids, or inorganic contaminants. Interestingly, this extensive monitoring program revealed that 51% of the wells contained coliform bacteria (i.e., not due to oil and gas wells).

As a result of the explosion, permit conditions for all oil and gas wells in the DMRM jurisdiction were revised to cover the full range of potential conditions in the casing annulus that could over-pressurize a well.

EPA plans to contact OHDNR to determine whether hydraulic fracturing may have affected or promoted gas migration and/or over-pressurization.

Pennsylvania

McKean County

The description of the incident was summarized from a May 4, 2009 news release from the Pennsylvania Department of Environmental Protection (PA DEP) (PA DEP, 2009d). This news release also serves as the primary source for the state and drilling company's response to the incident, with additional information taken from a January 23, 2009 news article in the *Bradford Era* (Vosler, 2009).

Summary-Bradford Township

PA DEP found methane in the well water of two homes, and levels of iron and manganese above drinking water standards in five other wells located along Hedgehog Lane in Bradford Township, McKean County (PA DEP, 2009c). At the time of the investigation, methane was still present at one well, and as a precautionary measure, the resident was staying at a motel. PA DEP determined that Schreiner Oil and Gas Company was responsible for the contamination. Schreiner has been actively drilling oil and gas wells in the area since the fall of 2008 and failed to establish background water quality before drilling. Therefore, PA DEP is requiring the company to restore water supplies within 1,000 feet of its drilling sites.

Actions Taken

During its investigation, PA DEP assessed 17 wells (PA DEP, 2009c). When the PA DEP news release was published (May 4, 2009), PA DEP was still conducting daily monitoring at the well with the high methane readings and had observed a decrease in methane levels over time. PA DEP has issued several notices of violation (NOVs) to Schreiner for failure to submit well records, over pressuring wells, pit violations, and failure to post a well permit.

PA DEP suspects that the methane migration was caused by 26 recently drilled wells, "four of which had excessive pressure at the surface casing seat", with the other 22 lacking cement returns. Schreiner has installed packers on all hydraulically fractured wells and vented drilled wells that have not yet been hydraulically fractured. Schreiner is prohibited from drilling any new wells until the methane migration issue is resolved.

According to a January 23, 2009 news article in the *Bradford Era*, homeowners noted that hydraulic fracturing activity took place during the PA DEP ban and that noise, odor, and water well issues persisted (Vosler, 2009). In this article, Schreiner states that it has made over $100,000 worth of improvements and completed all the work required by the PA DEP, such as planting trees to abate noise near equipment. However, the town supervisor noted that the company did not take steps that were originally agreed upon, such as building a shed around the equipment to control noise. Town officials were discussing the possibility of connecting homes to a public water system.

EPA plans to contact PA DEP to determine if hydraulic fracturing contributed to the methane migration.

Summary – Gibbs Hill

Information regarding private well contamination believed to be due to drilling operations was summarized from an August 11, 2008 news article in *The Ridgeway Record* (Zemack, 2008); a 2008 article published in the *Newburgh Advocate*; and a PA DEP NOV (PA DEP, 2008), which was cited in July 23, 2009 correspondence from NRDC to USEPA (NRDC, 2009). A copy of the PA DEP NOV was not available on the internet nor reviewed for this report.

Several homeowners in Gibbs Hill reported changes in their water quality following hydraulic fracturing of nearby gas wells by Seneca Resources in the summer of 2008. Complaints included burning sensation, headache, or difficulty with sinuses after consuming the water or showering, a briny taste, and a gas-like smell. Prior to drilling, one homeowner, Stever Hilyer, warned Seneca that the planned gas well was too close to his spring (it was drilled approximately 800 feet away) (Zemack, 2008). According to the *Newburgh Advocate* article, the Hilyers had their water tested prior to and after the gas well was drilled. Analysis of the post-drilling sample(s) indicated a barium concentration of 3.30 mg/L (above EPA's MCL of 2 mg/L) and high levels of manganese and total dissolved solids (the article does not indicate who collected and analyzed the post-drilling samples). Two other homeowners reported that drilling operations caused their "private water supply" to dry up (Zemack, 2008).

Actions Taken

PA DEP tested the water; however, no information was provided regarding the types of analyses run or the analytical results. PA DEP provided homeowners with bottled water and a 2,000 gallon tank of non-potable water for washing and toilet flushing, which has occasionally malfunctioned (Zemack, 2008). At the time the August 11 news article was published, PA DEP was continuing to monitor the spring and had not concluded whether it was permanently damaged. Under the Pennsylvania Oil and Gas Act, companies that drill within 1,000 feet of a private water supply must restore or replace a resident's water supply if their operations impact it (Zemack, 2008). Seneca drilled a new well for one homeowner whose well went dry. The new well caught fire, was capped off, and was unable to be used for several months until the natural gas burned off.

According to the 2008 PA DEP NOV that is referenced by NRDC (2009), the PA DEP found that pressure in the gas well had exceeded the pressure in the surrounding fresh ground water system and that there had been unpermitted discharge of hydraulic fracturing fluids (PA DEP 2008, as cited in NRDC, 2009). EPA plans to follow-up with PA DEP to obtain more information regarding the testing that was performed by the state and to confirm whether pressure in the gas well resulted in an unpermitted discharge of hydraulic fracturing fluids.

Summary – Hamlin Township

Limited information regarding an explosion in a drinking water well was summarized from a September 19, 2007 article published in the *Kane Republican* (Lutz, 2007). Gas drilling is blamed for causing natural gas to seep into the Kushequa community water well, resulting in an explosion inside the water well. The article indicates that several blasts rocked the well, sent a vent cap flying more than 10 feet, and flipped a half-inch thick, 120-pound steel lid off the opening of the well. The 96-foot deep well, drilled in 1992, served 14 residential customers, including six permanent homes and eight camps. A PA DEP test showed a reading of 64 percent gas inside the manhole at the community well.

Actions Taken

According to the news article, the PA DEP advised residents to buy bottled water while the state pushed drillers to provide a temporary water supply for residents until an investigation is completed (Lutz, 2007). PA DEP also advised residents to keep vents open on the community well, along with private wells to prevent gas buildup. The PA DEP planned to conduct an investigation of the active gas and oil wells in the Kushequa area, but indicated that gas may be entering natural crevices in the mountainous terrain and through uncharted and abandoned oil wells drilled perhaps a century ago (Lutz, 2007). No further information on a follow-up investigation was available. EPA plans to contact PA DEP to discuss the status of the state's investigation, whether hydraulic fracturing was used by the oil and gas companies in the area, and if so, its possible link to the gas migration into the community's water well.

Dimrock Township (Susquehanna County)

Methane contamination found in some private wells in Dimrock Township is based on information from a notice of violation (NOV) issued by PA DEP to Cabot Oil and Gas (PA DEP, 2009a), testimony presented by PA DEP to the Senate (PA DEP, 2009b) on gas exploration in the Marcellus Shale formation in Pennsylvania and protection of the state's waters, and a January 26, 2009 article in *The Times Leader* (Sweeney, 2009). Information describing citizens' concerns about fracturing fluid contamination is summarized from a March 13, 2009 *Reuters* article (Hurdle, 2009).

Summary

On January 1, 2009, the cap of a "water well pit" in Dimrock Township exploded (PA DEP 2009b; Sweeney, 2009). The well is located within a quarter mile of the several drilling sites that are operated by Cabot Oil and Gas (Sweeney, 2009). This incident prompted an investigation by PA DEP and is discussed in more detail below.

According to a March 13, 2009 *Reuters* article, some residents are concerned that hydraulic fracturing fluids are also contaminating the area's wells, causing cloudy or brown water, and illness in people ("persistent diarrhea and cramps") and animals (e.g., hair loss). Three of the four individuals whose complaints were featured in the article have methane detectors provided by Cabot in response to a NOV (see Actions Taken below).

Actions Taken

Since January 2009, PA DEP has conducted dissolved methane analyses of samples collected from the private wells of approximately 24 homes (PA DEP, 2009b). Four of the nine impacted wells have methane levels that "could pose a threat of explosion in enclosed areas of the home" (PA DEP, 2009b).

In addition, PA DEP issued a NOV to Cabot on February 27, 2009 (PA DEP, 2009a) related to methane migration for the company's failure to prevent natural gas from entering fresh ground water in the Carter Road area, failure to submit well record and completion reports for 23 oil and gas wells, and failure to submit a plugging certificate for one oil and gas well (PA DEP, 2009a, 2009b). The NOV requires Cabot to install methane gas detectors in nine homes and provide bottled water to four homes until the PA DEP determines that the well water is safe to drink. The NOV also requires Cabot to provide the PA DEP with the analytical results from all water samples collected by the company and to provide homeowners with their specific results. PA DEP required Cabot to resolve the violations by March 10, 2009. The NOV does not mention whether Cabot uses hydraulic fracturing in its oil and gas operations.

To help prevent gas migration, Cabot implemented a new casing and cementing protocol for new gas wells and added additional cement sealers for existing wells (PA DEP, 2009b). PA DEP indicated that its staff has been inspecting existing

wells, monitoring new drilling, continuing to collect residential water samples, and inspecting property for the "presence of fugitive gas" (PA DEP, 2009b).

PA DEP has also analyzed several water samples for total dissolved solids, chlorides, specific conductivity, pH, alkalinity, hardness, sodium, calcium, barium, manganese, potassium and aluminum and determined that none "were found in levels that would indicate that liquids used to fracture natural gas wells have migrated to ground water (PA DEP, 2009b). Additional sampling for contaminants will be included as part of the state's ongoing investigation and in response to new complaints (PA DEP, 2009b).

PA DEP also explained that the public and press are incorrect in their belief that the chemicals used for hydraulic fracturing are unknown (PA DEP, 2009b). Instead, drillers must disclose all chemicals used at well sites as part of their permit application. In addition, the information is provided to area emergency responders and as public record. PA DEP recently posted a list of fracturing fluid chemicals on its website.

EPA plans to contact PA DEP to obtain information about the state's ongoing investigations, the nature of new complaints reported to the state, and whether the specific cause of the well contamination has been determined, including any link to hydraulic fracturing.

Millcreek Township (Erie County)

Information on an incident involving methane contamination in Millcreek Township was summarized from PA DEP's July 8, 2009, *Daily Update* (PA DEP, 2009d) and a July 16, 2008 article published in the *Erie Times News* (Bruce, 2008). Neither article provided details regarding driller operation or exact locations of the gas wells.

Summary

According to the PA DEP *Daily Update*, five families on and near Head Drive were instructed by Millcreek emergency management officials to leave their homes on November 20, 2007, after natural gas levels in and around their homes were measured at explosive levels (PA DEP, 2009d). Natural gas was also found to have migrated to Walnut Creek. These families were unable to return to their homes for 39 days. PA DEP discovered during its investigation that First Alliance Church, located near Head Drive, had hired a contractor to drill several natural gas wells on its property (PA DEP, 2009d).

According to a July 16, 2008 *Erie Times News* article, the degradation in the quality of one homeowner's well water after the methane contamination forced him to replace his filters several times per month instead of quarterly (Bruce, 2008). The article also indicated that the state tested his well water and found "iron, manganese and other contaminants above the standards for safe drinking water" and enough methane to pose a "physical danger of fire or explosion."

Actions Taken

PA DEP ordered First Alliance Church to plug the well that was determined to be the source of drinking water contamination (PA DEP, 2009d). Gas levels dropped after the well was plugged, allowing families to return to their homes on December 28. PA DEP also assessed a civil penalty of $32,000 against First Alliance Church for the gas migration incident.

According to the *Erie Times News* article, PA DEP attributes the iron and manganese contamination in at least two drinking water wells to the compressed air used "to force drill cuttings back to the surface" (Bruce, 2008). PA DEP believes that the air infiltrated porous iron-bearing rock, making the iron soluble and allowing it and other contaminants to migrate into wells.

EPA plans to contact PA DEP to determine whether hydraulic fracturing was used in the construction or operation of the First Alliance Church gas wells, to learn what operational or well conditions resulted in the methane contamination, and to confirm the cause of the iron and manganese contamination.

Texas

Very limited information was available from two sources that describe contamination believed to be associated with oil and gas activity in Fort Worth, Texas. Information from a September 17, 2008 article in the *Christian Science Monitor* (Clayton, 2008) and a May 27, 2009 report posted on *National Public Radio's* website (Brady, 2009) are presented below. Neither article indicates whether state officials responded to the complaint.

Summary

Charlotte Harris reported that her drinking water well was contaminated when a new gas well was being hydraulically fractured 100 yards from her house (Clayton, 2008). The Harrises expressed concern that fracturing fluids may be the cause of the contamination (Clayton, 2008). She and her husband indicated that their shower water had a "sulfurous odor" (Brady, 2009; Clayton, 2008), irritated Charlotte Harris' skin (Clayton, 2008), and caused a rash on their grandson (Brady, 2009). Mr. Harris also stated that his horses stopped drinking the water and that water erupted from his toilet upon flushing (Brady, 2009).

Actions Taken

Information on the response to the incident by the drilling company, Williams Production-Gulf Coast Company, was limited to a statement in the September 17, 2008 *Christian Science Monitor* article (Clayton, 2008). According to this new source, the drilling company tested the drinking water and found no contamination (Clayton, 2008). The article also indicated that toluene was found by a laboratory that tested a neighbor's well water but did not specify the concentration of toluene detected. It noted that toluene is "often used in drilling fluids".

Wyoming

Pavillion, Freemont County

Information regarding private drinking water well contamination in Pavillion, Wyoming and subsequent follow-up actions from Encana, the Wyoming Department of Environmental Quality, and EPA Region 8 were based on: a January 2009 draft communication strategy developed by Region 8 (EPA, 2009); a July 8, 2009 follow-up phone discussion with EPA Region 8 (Wiser, 2009); a PowerPoint presentation prepared by Universal Geosciences specific to one of the contaminated wells (Gorody, no date); a record of communication between Region 8 and Wyoming Oil and Gas Conservation Commission; and a July 21, 2008 newspaper article in the *Star-Tribune* (Merrill, 2008).

Summary

Residents of Pavillion, Wyoming have expressed concerns about private drinking water well contamination that they believe is tied to natural gas development in their area (EPA, 2009). Pavillion is in Freemont County, within the Wind River Indian Reservation, approximately 20 miles from the Riverton metro area. (There is, however, some question whether Congressional actions have reduced the Reservation's acreage such that Pavillion may lie outside its boundary.) It has approximately 166 residents (EPA, 2009).

Pavillion has approximately 80 wells used for drinking water, irrigation, and stock watering, and the wells are 50 to 400 feet deep (EPA, 2009). The gas and oil development in Pavillion is on privately owned agricultural and ranching lands (Merrill, 2008). The oil and gas rights are owned mostly by tribes in the area, and most of those rights have been sold or leased to EnCana by the tribes (Merrill 2008).

According to a July 21, 2008 *Star Tribune* article, an organizer for the Pavillion Area Concerned Citizens noted that approximately eight wells are contaminated and cannot be used for human or animal consumption (Merrill, 2008). No information was reported regarding the type of contamination. The article went on to state that the wells are located on four families' properties (Louis Meek, the Walkers, the Garners, and the Foxworthys). The article noted that a few residents cited symptoms including the loss of senses of taste and smell, and "strange and random symptoms that they can't pin down." Residents believe that their health issues are related to oil and gas development in the Pavillion-Muddy Ridge gas field area in Sublette County, Wyoming. One resident is more concerned about air pollution and cites noxious smelling fumes downwind of the wells and indicated that all emissions from the oil and gas company in the area (EnCana) are not

vented before release into the atmosphere. (It is important to note that none of the other documents reviewed discussed EnCana's practices for handling emissions.)

Actions Taken-WY DEQ and EnCana

A case study on Louis Meeks' well was prepared by Gorody (apparently under contract to EnCana) (Gorody, no date). The Gorody study summarizes the site and area geology, reviews available surface and ground water analysis data (including data from the USGS, the WY DEQ, and EnCana), and reviews the characteristics (e.g., geometry and depth) of the gas-bearing reservoirs subject to hydraulic fracturing in the area. In part due to the format of the Gorody case study (a PowerPoint presentation with no slide notes or context), some of the data, information, and details are ambiguous. Therefore, not all of the findings and conclusions can be directly and/or thoroughly assessed. For example, the locations of some of the ground water samples are unclear, and the timing of sample collection with respect to hydraulic fracturing activities is not indicated.

Mr. Meeks' drinking water well reportedly has experienced a decreased yield and has taste and odor problems. These problems are allegedly due to gas production activities related to EnCana's Pavillion 24-02 well. Gorody concludes that the general geology indicates that there is no "vertical communication" between the deep Pavillion 24-02 fracturing horizons and Mr. Meeks' shallow well. Gorody indicates there is an aquitard/fracture barrier separating the two wells, that measures of water quality in the Meeks well show no change since before the Pavillion well was operational, and that no hydrocarbons were found in samples from the Meek well. Gorody also states that gases in the Pavillion well are all of thermogenic (deep) origin, whereas the gases found in the Meeks well are of microbial (shallow) origin.

A record of communication between Dan Jackson of Region 8 and Craig Eggerman of the Wyoming Oil and Gas Conservation Commission (WOGCC) provide additional background on Louis Meeks' well (Jackson, 2008). Prior to drilling the well, Louis Meeks was warned by the State Engineer of the high probably of drilling into the same gas zone that impacted his other water well and was encouraged to follow the WOGCC's recommended drilling protocols. While drilling the well, the protocols were not followed. The well was drilled too deep into a gas zone "that kicked out of control", and the drilling rig was ignited. EnCana saw the incident and independently called in help to extinguish the fire.

According to the previously referenced July 21, 2008 article in the *Star-Tribune*, the WY DEQ, confirmed that at least two private drinking water wells are contaminated, and a few other wells may also be contaminated (Merrill, 2008). Monitoring activity has been focused on one well that is yielding foul-smelling and oily water (the article does not specifically identify this well as Louis Meeks' well). Samples from the well indicate that iron bacteria and not hydrocarbons may be responsible for the smell and the appearance of the water. One sample also indicated trace amounts of glycol, which may be the result of laboratory contamination. At this point, DEQ has not been able to establish a connection between oil and gas activity and the contaminated wells. The article also indicates that the WY DEQ has requested additional monitoring from EnCana. The article quotes Mark Thiesse, district supervisor for the WY DEQ's water quality division, as saying, "One of our working hypotheses is that the oil and gas activity has introduced something into the sub surface that has increased the bacteria in this well." The WY DEQ also plans to investigate another incidence of contamination where a well produces "water that turns black after being drawn, and leaves black, orange and rust colored residue on the water filter" (Merrill, 2008).

Actions Taken-EPA Region 8

EPA's involvement in investigating the cause and extent of the contamination is supported by the WY DEQ and other local agencies, including the town's mayor. A few citizens from Pavillion contacted EPA about possible well contamination and reported that they felt that other agencies had not adequately addressed their concerns (EPA, 2009).

Using its sample collection authority, EPA Region 8's Superfund Program collected samples from 40 water wells in the area (Wiser, 2009). In samples from five wells, the analyses found 'tentatively identified compounds' (TICs) (i.e., the analyses found the definite presence of some compounds, but it was not possible to determine the identity or concentration of the unknown compounds). No BTEX or other regulated drinking water contaminants were found, but caprolactam was found in some samples. The Region plans to retest the wells with TICs and obtain the standards needed to identify and quantify the unknown contaminants. However, it is unknown if EPA Region 8 will be able to obtain a sample of the fracturing fluid (Wiser, 2009). In addition, the Region plans to notify individuals in whose samples caprolactam was detected that this compound was not found at harmful levels. At this point, EPA has not reached any conclusions as to whether or not the contamination is related to hydraulic fracturing (Wiser, 2009).

EPA Headquarters will obtain an update from EPA Region 8 regarding its investigation into the cause, extent, and nature of the contamination. EPA Headquarters also plans to contact WQ DEQ regarding these issues.

Sublette County

Information regarding contamination in the Pinedale Anticline Project Area (PAPA) was based on a November 17, 2008 *Denver Post* article (Lustgarten, 2008); May 2009 fact sheets developed by Chesapeake Energy (Chesapeake Energy, 2009); and an EPA Region 8 Proposed Agenda for Oil & Gas GW Impacts Coordination Meeting that was scheduled for July 29, 2008 (USEPA, 2008).

The Pinedale Anticline Project Area (PAPA) is a 308-square mile natural gas field in west-central Wyoming in Sublette County near Pinedale (Chesapeake Energy, 2009). According to Chesapeake Energy, the "uppermost gas-bearing geologic formations of economic significance are located 8,000 feet below the ground surface." Most wells in Sublette County are on federal land, and the Bureau of Land Management (BLM) handles leasing and permitting for gas development (Lustgarten, 2008).

According to EPA, more than 80 water wells in Pinedale are contaminated with benzene, of which 14 exceed the MCL (the measured levels were not specified) (USEPA, 2009). According to Lustgarten (2008), benzene levels in the wells were more than 1,500 times the MCL. Both the Region and Chesapeake Energy indicated that none of the contaminated wells are used for drinking water. However, the Region indicated that these wells are sited in a drinking water aquifer. At least two public water system wells are within the contaminated area, and whether testing for benzene has occurred at these sites is unknown (USEPA, 2008). The Region noted that the area of benzene contamination extends 30 miles. The Region became aware of the benzene ground water contamination during a May, 2008 public meeting on the draft environmental impact statement (EIS) for Pinedale. The draft EIS includes a proposal to add 4,000 gas wells to the approximately 800 existing wells. According to the Lustgarten article (2008), BLM approved plans for 4,400 new wells in Sublette County, despite the unresolved water issues and despite objections from EPA.

Lustgarten (2008) also reported that high levels of fluoride were found in private drinking water "wells adjacent to the anticline drilling". Furthermore, Lustgarten noted that fluoride is included in Halliburton's hydraulic fracturing patent applications. The article does not indicate whether high fluoride levels are unusual for the area or if they could be due to natural sources. Neither the EPA nor Chesapeake Energy documents reviewed discuss high fluoride levels.

According to Chespeake Energy (2009), the 2000 BLM EIS and Record of Decision (ROD) requires natural gas well operators to collect and analyze samples of all wells within a one-mile radius of existing and proposed natural gas wells. However, EPA Region 8 indicated that BLM has been sued for failing to meet the terms of its 2000 EIS and ROD, including failure to implement ground water monitoring (USEPA, 2008).

Chesapeake Energy (2009) indicates that Federal agencies have not determined that hydraulic fracturing caused the contamination, and that the investigation centers on "backflow prevention devices between storage tanks and industrial water wells, the use of hydrocarbon-based pipe dope compounds in well construction, problematic water well drilling techniques, and natural sources of contamination" (Chesapeake Energy, 2009). EPA Headquarters will obtain an update from EPA Region 8 regarding the investigations that have been conducted to determine the cause, nature, and extent of contamination.

Conclusions and Recommended Next Steps

This report presented several incidents of ground water contamination that occurred near oil or gas production well sites. The types of complaints found in the review of these incidents included: changes in water quality (murky, oily, rusty, foul tasting or smelling, the presence of methane), changes in water quantity, consumption of the water causing illness in people (e.g., adrenal tumor, nausea, headaches), and rashes after showering. Some complaints were related to air emissions from the drilling sites.

The available documentation varied greatly in quality and detail, ranging from brief descriptions of the incident to detailed investigative reports by state agencies. Some private well owners specifically reported hydraulic fracturing as the cause of

their contamination, while the details of other reported incidents were more vague. Some reports did not clearly identify whether hydraulic fracturing was used in the construction or operation of the gas production well, or wells, associated with the reported (or alleged) problem; others did not explicitly identify or rule out hydraulic fracturing as the specific cause of impacted ground water. Confounding factors included other gas production-related releases that were also reported by citizens and state agencies including accidental spills during operation and transport, improper management and construction of by-product fluid impoundment pits, improper burning of wastes, and air emissions.

The available evidence on the studied cases is not sufficient to confirm or rule out hydraulic fracturing as the source of impacted or contaminated ground water. Hydraulic fracturing is one of several stages in the construction and operation of an oil or gas production well that could potentially impact (contaminate) ground water. Therefore, to definitively link reported ground water contamination exclusively to a hydraulic fracturing event will likely require significantly more information than is typically provided in the cases assessed for this report.

The type of information that might be needed includes specific information on the production and drinking water wells involved (e.g., well construction and depth details, the characteristics and timing of hydraulic fracturing events and of the incidence(s) of ground water/drinking water contamination, the composition of the hydraulic fracturing fluids used), information of the site-specific geology and hydrogeology (e.g., ground water flow characteristics across the area of the production and drinking water wells in questions, the anticipated fate and transport of hydraulic fracturing fluids following injection, site fault and fracture system characteristics), and details of the ancillary surface operations (e.g., construction and operation details of surface pits, characteristics/timing of material handling spills or releases, composition of materials).

Two data-collection efforts are recommended as next steps:

- Contact EPA regional offices, state regulatory agencies and other key individuals, to obtain additional follow-up information on 12 reported cases of contamination that may have a link to hydraulic fracturing.

- Collect field data at one or more sites before, during, and after a hydraulic fracturing stimulation including, ideally, ground water sampling relatively near the production well that is fractured.

Each of these recommendations is discussed in more detail in separate subsections below

Contact Key Individuals, Organizations, and Agencies

The table below provides a suggested list of individuals and/or agencies that may be able to provide additional information that will help to confirm or eliminate hydraulic fracturing as a cause for a specific reported incident of ground water contamination.

Suggested Contact List for Follow-up		
Name	**Affiliation**	**Contaminant Case for which Contact May Have Relevant Information**
EPA and other Federal Agencies		
Karen Johnson	EPA Region 3	• Bradford Township, PA • Gibbs Hill, PA • Hamlin Township, PA • Dimrock Township, PA • Millcreek Township, PA
TBD	EPA Region 5 – UIC Program	• Bainbridge Township, OH
TBD	EPA Region 6 – UIC Program	• New Mexico
Dan Jackson	EPA Region 8 – UIC Program	• Huerfano County, CO • LaPlata, CO • Pavillion, WY • Pinedale, WY
Nathan Wiser	EPA Region 8 – UIC Program	• Huerfano County, CO • LaPlata, CO • Pavillion, WY

Suggested Contact List for Follow-up		
Name	**Affiliation**	**Contaminant Case for which Contact May Have Relevant Information**
		• Pinedale, WY
Luke Chavez	EPA Region 8 – Superfund Program	• Pinedale, WY
Tom Rice	Bureau of Land Management	• Pinedale, WY
State Regulatory Agencies		
TBD	Pennsylvania Department of Environmental Protection (PA DEP)	• Bradford Township, PA • Gibbs Hill, PA • Hamlin Township, PA • Dimrock Township, PA • Millcreek Township, PA
Dave Dillon	Colorado Oil and Gas Conservation Commission (COGCC)	• Huerfano County, CO
Steve Lindblom	COGCC	• LaPlata, CO
Mark Fesmire	New Mexico Oil Conservation Division – Director	• New Mexico
TBD	Ohio DNR, Division of Mineral Resources Management	• Bainbridge Township, OH
TBD	Texas Railroad Commission	• Grandview Johnson, TX
Craig Eggerman	Wyoming Department of Environmental Quality (WY DEQ)	• Pavillion, WY
Mark Thiesse	Wyoming Department of Environmental Quality (WY DEQ)	• Pavillion, WY
Other		
Anthony Gorody	Universal Geosciences	• Pavillion, WY

EPA will develop questions that are specific to each case. Below are examples of some of the information that EPA may request:

- Background information related to the general geology, hydrogeology, and stratigraphy; the depths and flow directions of aquifers or USDWs in the area; the possible presence of faults, fracture systems, or other features (such as abandoned wells) that can act as conduits for hydraulic fracturing fluid or methane migration; the depths of gas reservoirs, and; the depths of the screened intervals of drinking water wells and the production intervals of the gas wells.
- Whether the gas well believed to be the source of contamination was hydraulically fractured, and any other well operational information (e.g., well integrity problems) relevant to the potential release of chemicals into ground water.
- Specific details pertaining to ground water investigations conducted or planned in response to the reported incident including: water sample locations, dates, parameters, and results; whether constituents of fracturing fluids are known and included in the sample parameters, and; timing of water samples relative to hydraulic fracturing events.
- Any conclusions by the investigating agency regarding the extent or cause of contamination (e.g., operational or well conditions), whether hydraulic fracturing was determined to be or not to be the cause of the contamination, or the information on which the conclusions were based.
- Whether hydraulic fracturing fluids were among the contaminants that were improperly managed or stored in reserve pits.

EPA will provide a summary of the information obtained from the list of contacts in an addendum to this report.

Conduct One or More Field Studies

In his study of the Mamm Creek Field Area in Garfield County, Colorado, Thyne (2008) identified issues that could serve as general considerations for investigations of suspected or alleged cases of ground water contamination due to hydraulic fracturing. He concluded that given the nature of the information reviewed, it was difficult to assign responsibility of

ground water impacts to specific gas wells: "The number of water wells (<200) and their spatial distribution is inadequate to monitor and locate potential source of contamination from the more than 1400 potential point sources (gas wells and produced water pits)." While detailed regional geological and hydrogeological background information is necessary (such as the information presented in the CO Phase I and II reports), this type of information is likely not sufficient for definitively linking specific hydraulic fracturing activities to specific cases of impacted ground water (and typically is not sufficient for ruling out hydraulic fracturing activities as the source of ground water impacts).

Field studies designed and appropriately timed to sample ground water near wells conducting hydraulic fracturing might be necessary for generating the type of ground water sample data that could empirically characterize the fate and transport of injected hydraulic fracturing fluids. Should the Agency consider proceeding with a field monitoring/sampling program, partnerships with states, industry, and experts would be important to assist with planning and execution of the program.

References

Brady, Jeff. Face-Off Over 'Fracking': Water Battle Brews On Hill. *NPR*. Available at: http://www.npr.org/templates/story/story.php?storyId=104565793&ft=1&f=1014.

Bruce, David. Water woes, Wells contaminated at site of gas leak. *Erie Times News*. July 16, 2008. http://www.goerie.com/apps/pbcs.dll/article?AID=/20080716/NEWS02/807160332/-1/NEWS.

Chesapeake Energy. May 2009. "Frac vs. Fiction". http://s3.amazonaws.com/propublica/assets/natural_gas/frac_fiction_may2009.pdf.

Clayton, Mark. Controversial path to possible glut of natural gas. The *Christian Science Monitor*. http://features.csmonitor.com/environment/2008/09/17/controversial-path-to-possible-glut-of-natural-gas.

Clearwater International, LLC. MSDS Data Sheet for Zeta Flow. January 27, 2009. http://www.msds.com.

COGCC 2005a. Notice of Hearing in the Matter of Alleged Violations of the Rules and Regulations of the Colorado Oil and Gas Conservation Commission by Encana Oil & Gas USA, Inc., Garfield County, Colorado. Cause No. 1V, Docket No. 0507-Ov-07, June 10, 2005. http://cogcc.state.co.us/Hearings/Notices/2005/Jul05/0507-OV-07Notice.pdf.

COGCC. 2005b. COGIS NOAV Report. Issued by COGCC to Maralex Resources Inc. COGIS document number 200085988. October 30, 2005. http://oil-gas.state.co.us/cogis/NOAVReport.asp?doc_num=200085988.

COGCC. 2007. Report of the Commission: Emergency hearing before the Commission for an order to allow the expenditure of additional funds from the Oil and Gas Conservation and Environmental Response Fund. Cause No. 1E, Order No 1E-6, July 23, 2007. http://cogcc.state.co.us/orders/orders/1E/6.html

Earthworks. (No date). Groundwater Contamination http://www.earthworksaction.org/NM_GW_Contamination.cfm#COUNTIES

Halliburton Energy Services. Material Safety Data Sheet for Ethylene Glycol Monobutyl Ether. January 2, 2007. http://www.msds.com/.

Hurdle, John. U.S. energy future hits snag in rural Pennsylvania. *Reuters*. March 13, 2009. http://www.reuters.com/article/domesticNews/idUSTRE52C07920090313?pageNumber=1&virtualBrandChannel=0.

Iger, Michael. Staffer for Representative Maurice Hinchey of New York. Personal Communication. July 14, 2009.

Interstate Oil and Gas Compact Commission. June 2009. Regulatory Statements On Hydraulic Fracturing Submitted By The States. Downloaded at http://www.iogcc.state.ok.us/Websites/iogcc/Images/2009StateRegulatoryStatementsonHydraulic%20Fracturing.pdf (ref 39)

Lustgarten, Abrahm. "Drilling process causes water supply alarm." *Denver Post* 17 Nov 2008. ProPublica. http://www.denverpost.com/ci_11001835.

Lutz, Ted. Gas Explosions Rock Kushequa Water Well. *The Kane Republican*. September 19, 2007. Available at: http://www1.kanerepublican.com/index.php?option=com_content&task=view&id=7335

Mall, Amy. National Resources Defense Council. Personal Communication. July 9, 2009.

Merrill, Chris. Contaminated wells concern Pavillion-area residents. *Star-Tribune*. July 21, 2008. Available at: http://www.casperstartribune.net/articles/2008/07/22/news/wyoming/da662aeaf6aec8b48725748c00210db4.txt.

Mall, Amy, Sharon Buccino, and Jeremy Nichols. "Drilling Down, Protecting Western Communities from the Health and Environmental Effects of Oil and Gas Production". NRDC. October, 2007. http://www.nrdc.org/land/use/down/down.pdf.

Moscou, Jim. A Toxic Spew? Officials worry about impact of 'fracking' of oil and gas. Newsweek Web Exclusive, Aug 20, 2008. http://www.newsweek.com/id/154394.

Natural Resources Defense Council (NRDC). July 23, 2009 Correspondence from Amy Mall and Sharon Buccino, NRDC to Steve Heare, Jeff Jollie, and Ann Codrington, USEPA.

Ohio Department of Natural Resources, Division of Mineral Resources Management. 2008. Report on the Investigation of the Natural Gas Invasion of Aquifers in Bainbridge Township of Geauga County, Ohio. http://s3.amazonaws.com/propublica/assets/natural_gas/ohio_methane_report_080901.pdf.

Papadopulos, 2008. Phase II Hydrogeologic Characterization of the Mamm Creek Field Area, Garfield County, Colorado.

Pennsylvania Department of Environmental Protection. (date unknown). Notice of Violation, Insp. ID 1727711, Enforcement ID 237069.

Pennsylvania Department of Environmental Protection. 2009a. Notice of Violation. February 27, 2009. Available at: http://s3.amazonaws.com/propublica/assets/methane/pdep_nov_cabot_090227.pdf.

Pennsylvania Department of Environmental Protection. 2009b. Testimony - J. Scott Roberts, Deputy Secretary for Mineral Resources Management Department of Environmental Protection before the Senate Majority Policy Committee. April 9, 2009. http://www.depweb.state.pa.us/dep/lib/dep/test_040909_senpolicy1.doc.

Pennsylvania Department of Environmental Protection. 2009c. DEP Identifies Responsibility for Bradford Township Gas Migration/Water Supply Problems. May 4, 2009. http://www.ctbpls.com/www/PA/library/2009/2009050457.HTM

Pennsylvania Department of Environmental Protection. 2009d. *Daily Update*. DEP Assesses Penalty for 2007 Gas Migration That Forced Evacuations in Erie County. July 8, 2009. http://www.depweb.state.pa.us/news/cwp/view.asp?a=1278&q=547606.

Slothower, Chuck. Gas Worker: Chemical not to blame. *Durango Herald*. July 23, 2008. http://durangoherald.com/sections/News/2008/07/23/Gas_worker_Chemical__not_to_blame/.

Stevens, Laura. Dirty well water raises stink near drilling sites - Residents cite gas firm for poor quality. *Arkansas Democrat-Gazette* 07/05/2009. http://www2.arkansasonline.com/staff/laura-stevens.

Sumi, Lisa. Summary of Recent Incidents Involving the Release of Chemicals. June 2006. http://www.earthworksaction.org/pubs/INCIDENTS.pdf.

Sweeney, Rory. Source of Gas in Dimock Twp. Wells Unknown. *The Times Leader* (Wilkes-Barre, PA). January 26, 2009. http://www.istockanalyst.com/article/viewiStockNews/articleid/2980793.

The Newburgh Advocate. High Stakes in the Empire State: Ambitious Gas Drilling Projects Promise Revenue but Threaten Environment. Available at: http://www.newburghadvocate.com/2008/12/30/high-stakes-in-the-empire-state-ambitious-gas-drilling-projects-promise-revenue-but-threaten-environment/.

Thyne, Geoffrey. 2008. Review of Phase II Hydrogeologic Study Prepared for Garfield County.

URS Coporation, 2006. Phase I Hydrogeologic Characterization of the Mamm Creek Field Area, Garfield County

USEPA. 2004. Evaluation of Impact to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs.

US House of Representatives. Stenographic Minutes from the Interior, Environment, and Related Agencies Appropriations for 2010 – Environmental Protection Agency. May 19, 2009

Vosler, Adam. *Bradford Era.* Bradford Twp. looks to take action on Hedge Hog Lane issues. June 23, 2009. http://www.bradfordera.com/articles/2009/05/09/news/doc4a04dfa1a4c03017514557.txt.

Wiser, Nathan. Environmental Scientist. EPA Region 8. Personal communication. July 15, 2009.

Zemach, Heidi. Gibbs Hill Homeowners Lose Water Supply After Fracking. *The Ridgeway Record.* August 11, 2008. Available at: http://www.ridgwayrecord.com/content/view/144018/27/

Appendix A: Compilation of Search Terms Used to Identify Hydraulic Fracturing and Ground Water Contamination

General search terms

Hydraulic fracturing, fracing, fracking, shale gas, water contamination, ground water contamination, groundwater contamination, water/groundwater impacts, water/ground water impacts, ground water, USDW contamination, water/ground water pollution, water/groundwater pollution

Hydraulic fracturing, fracing, fracking, coal bed methane, coalbed methane, CBM, methane extraction, water contamination, ground water contamination, groundwater contamination, water/groundwater impacts, water/ground water impacts, ground water, USDW contamination, water/ground water pollution, water/groundwater pollution

Area-specific search terms (shale)

- Antrim Shale
- Barnett Shale
- Caney Shale
- Conesauga Shale
- Fayetteville Shale
- Floyd Shale
- Gothic Shale
- Haynesville Shale
- New Albany Shale
- Pearsall Shale
- Upper Devonian Shale
- Woodford Shale
- Marcellus Shale (PA/NY)

Area-specific search terms (coal bed methane)

- The San Juan Basin
- Black Warrior Basin
- The Piceance Basin
- The Uinta Basin
- Powder River Basin
- The Central Appalachian Basin
- The Northern Appalachian Basin
- The Western Interior Coal Region
- Raton Basin
- Sand Wash Basin
- Washington Coal Regions (Pacific and Central)

Agency-Specific

- Alaska Oil and Gas Conservation Commission
- Buchanan Citizens Action Group (VA)
- Catskill Mountain Keeper
- Colorado Oil and Gas Conservation Commission
- Damascus Citizens for Sustainability, Inc
- Delaware River Basin Commission
- Dickenson County Citizens Committee (VA)

- Ground Water Protection Council
- Indiana Department of Natural Resources, Division of Oil and Gas
- Interstate Oil and Gas Compact Commission
- Kentucky Division of Oil and Gas
- La Plata County Commissioners (Colorado)
- Louisiana Department of Natural Resources, Office of Conservation
- Michigan Office of Geological Survey (OGS)
- National Resource Defense Council
- Oil and Gas Accountability Project
- Oklahoma Oil and Gas Conservation Division
- Pennsylvania Department of Environmental Protection
- South Dakota Department of Environment and Natural Resource
- Susquehanna River Basin Commission
- Tennessee Department of Environmental Conservation
- Texas Railroad Commission
- Wyoming Oil and Gas Conservation Commission